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MEMORANDUM REPORT NO. 1181

DECEMBER 1958

SPIN COMPENSATION OF SHAPED CHARGE LINERS MANUFACTURED BY THE ROTARY EXTRUSION PROCESS (U)

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Attn: TISSS

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T. H. MARTIN

DEPARTMENT OF THE ARMY PROJECT NO. 5I0304009

ORDNANCE RESEARCH AND DEVELOPMENT PROJECT NO TB3-0134

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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BALLISTIC RESEARCH LABORATORIES

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JSimon/THMartin/is
Aberdeen Proving Ground, Md.
December 1958

SPIN COMPENSATION OF SHAPED CHARGE LINERS MANUFACTURED BY THE ROTARY EXTRUSION PROCESS (U)

(CONFIDENTIAL) ABSTRACT

Experiments were conducted with rotary extruded shaped charge liners to determine the effect of controlled manufacturing parameters on the "built in" metallurgical compensation effect, and to determine the highest compensation frequency that can be attained with this method of liner manufacture under present conditions. The optimum compensation spin-rate is shown to have a sequential shift with a variation in process parameters. These spin compensation frequencies are predicted from the examination of jets obtained by flash radiographic techniques. The optimum frequency for eleven lots of 90mm experimental liners varies with change of process parameters, and covers the range of frequencies from minus 25 rps to plus 35 rps. The predictions of optimum compensation frequencies are verified by penetration vs rotation experiments conducted at Picatinny Arsenal.

Results of the present test are compared with those of previous experiments, and the usefulness of the distortion angle as a specification for optimum compensation frequency is considered. The relative merits of rotary extruded and fluted liners under conditions where either can be used, are discussed.

(CONFIDENTIAL) I. INTRODUCTION

The penetration performance of shaped charge ammunition is degraded when the projectile is rotated. The deleterious rotation effects have been overcome by liners manufactured by the rotary extrusion process. This process results in spin compensation which minimizes the effects of rotation, but is effective only at low spin-rates. Previous experiments have indicated that an optimum spin compensation (the rotational frequency at which the best penetration performance of the round is obtained) depends on the manufacturing parameters. The Ballistic Research Laboratories conducted an investigation to determine whether or not a correlation actually exists between manufacturing parameters and optimum spin compensation.

In 1951, a group of shear-formed* copper liners fired statically (i.e., without rotation) at the Ballistic Research Laboratories gave poor penetration performance[1], and the jets observed radiographically were found to be badly fragmented[2,3]. To improve the metallurgical structure, the liner was heat treated to 900°C for one hour. When fired, these recrystallized liners gave improved penetration performance[1]. The poor static firing performance was largely eliminated by this heat treatment, and a jet which is normally fragmented was transformed to a continuous jet[4]. These improvements were not correctly interpreted until experiments by the Firestone Tire and Rubber Company revealed that liners from the same group (without heat treatment) showed a peak of penetration at a rotation frequency other than zero[5,6]. Subsequent penetration-rotation experiments with these shear-formed liners showed that they had a maximum penetration at a spin-rate of minus 45 rps[7]**. The existence of "built in" metallurgical spin compensation in the liners then was verified with flash radiography[3].

The results of two separate experiments at Firestone[6,8] suggested a correlation between the manufacturing parameters for rotary extruded liners and the observed spin compensation frequency. The spin compensation

* Process of liner manufacture.

** The convention for algebraic sign of direction of rotation has been taken as positive if the test projectile is rotated clockwise when viewed from the rear. This corresponds to a right hand twist of rifling in gun.

frequencies ranged from minus 15 rps to plus 30 rps. The Firestone reports indicate that the measure of distortion angle, θ, or metal displacement is dependent on the conditions of liner manufacture, and that the optimum spin-rate varies in a linear fashion with "θ".

The objective in this experiment was to reinvestigate the rotary extrusion process of liner manufacture under controlled and precise manufacturing conditions. The investigation extended over a wide range of distortion angles, θ. The ultimate goal was to determine whether "θ" was a true measure of the "built in" compensation, and to find the greatest value of optimum compensation frequency obtained with these rotary extruded liners.

The evaluation was a joint effort between Picatinny Arsenal and the Ballistic Research Laboratories. The program was divided into three phases:

(a) The determination of optimum compensation frequencies at the BRL by flash radiographic techniques, which is reported herein.

(b) The observation of optimum frequency determined independently at Picatinny Arsenal by penetration-rotation experiments which will be reported on seperately, and

(c) Investigation of the basic mechanism responsible for this metallurgical compensation which will be reported on separately by the BRL[9].

The determination of optimum frequencies (item a, above) by flash radiographic techniques yielded results with a minimum of testing time, since only a few firings were required, as compared to penetration experiments which require large amounts of target materials, and a large number of rounds to obtain performance data. The techniques used for flash radiography of jets from rotating charges have been described in previous reports[10,11].

(CONFIDENTIAL) II. LINER MANUFACTURE

A. Description of Process

The process of rotary extrusion employed at the Craft Manufacturing Company, Chicago, Illinois, which produced the liners tested, is illustrated in Figure 1. The operation starts by stamping and cupping a blank of OFHC* copper sheet, 3.5 inches in diameter, with an initial thickness of 0.225 inches (for a 90mm cone). The blank is centered in position on the mandrel. A live center clamps the liner material on the mandrel. With the blank in position, a freely rotating forming tool of carballoy steel (ten inches in diameter and one inch thick) is hydraulically moved toward the conical section of the live center. When the tool reaches the conical section, it is stopped and a microswitch contact starts it moving downward to form the cone. The material is shear-formed between the rotating mandrel and the roller of the forming tool to the desired liner specifications. (These particular liners are manufactured according to drawing PX-13-1910, cone 90mm T106846. The cone angle is 45° and final cone thickness is 0.093 inches). After the liner has been completed, the roller returns to its starting position, and another blank is inserted.

B. Parameters and Measurement of Deformation Angle

The manufacturing parameters of rate and direction of rotation of the mandrel during extrusion, and rate of feed of the forming tool may be varied independently, within the design limits of the equipment. The overall effect of these parameters is measured by the amount of metal displacement. During the process of rotary extrusion, the thickness of the blank material may be reduced 60% in one pass of the forming wheel. A twisting action is applied to the material as it is thinned. The metal displacement caused by the twisting action is designated as the deformation angle, θ[12]. This angle "θ" is determined by means of two lines scribed on the blanks at 90° to each other, and intersecting at the geometric center of the blank (apex of the cone) as shown in Figure 2a. The scribed blank is then rotary extruded with

* OFHC - oxygen-free high conductivity.

the scribed surface in contact with the rotating mandrel. A grid gage[12] designed by the manufacturer is inserted in the liner to measure "J" directly (see Figure 2b). The zero line of the grid gage at the 0.765" datum circle is aligned with each of the scribed lines on the cone. Readings for the angle "0" are taken at the intersection of the scribed line with the 2.629" datum circle on the grid gage. In Figure 2c, the deformation angle formed by the scribed lines with both clockwise and counter clockwise rotation of the mandrel, indicates the displacement of the scribed lines.

In order to vary the deformation angle, the manufacturer rotated the mandrel at 1800 rpm either clockwise or counter-clockwise, and varied the roller feed rate from 0.78 inches per minute to 17.02 inches per minute. This covered the range available with the existing rotary extrusion equipment. The nominal deformation angles were measured as follows: -15, -10, -5, 0, +5, +10, +15, +20, +25, +35 and +45 degrees. The manufacturing parameters and the resultant deformation angles are listed in Table I.

(CONFIDENTIAL) III. RESULTS AND DISCUSSION

A. Flash Radiography

Although flash radiographs were obtained for each lot of liners, a few illustrations should suffice to show the type of results obtained, and how they were evaluated. The optimum spin compensation was determined by the character of the jet structure. Continuous jets or jets having only slight longitudinal fragmentation indicate spin-rates near the optimum, while a severely fragmented or bifurcated jet indicates spin frequencies far removed from the optimum. The sequence of flash radiographs for lots A and K, the two extremes of the lots tested (deformation angles of minus 15° and plus 45°, respectively) are given in Figures 3 and 4.

The jets from unrotated charges for each lot, A through K, are shown in Figure 5. The radiographs are arranged by lots, in order of manufacture, from left to right. From pictures taken in this manner, the degree of spin compensation in a particular lot is indicated by the amount of fragmentation. The more severe the fragmentation and bifurcation, the greater the degree of "built in" spin compensation. The magnitude of spin compensation frequency cannot be interpreted from the radiographs in Figure 5. However, the qualitative nature of the jet, combined with the knowledge of manufacturing order, allows one to place the jets in the proper sequential arrangement. From the interpretation of the jet photographs, it can be seen that lot K (Figure 5K) has a higher spin compensation frequency than lot A (Figure 5a); the lots C and D (Figures 5c and 5d) have less spin compensation than lots A or K.

The performance data, based on estimates from all the radiographs, are presented in Table I. The optimum for each set of manufacturing parameters was estimated by interpolation from the radiographs, a symmetrical pattern about the optimum having been shown to exist in a sufficient number of cases to warrant the assumption that it exists in all cases. Tabulated with these data are the penetration-rotation performance data obtained at Picatinny Arsenal[13,15]. There is agreement, within the experimental error, between the

BRL predictions and those from firings conducted at Picatinny Arsenal. The penetration-rotation firings give a maximum penetration of 16 to 17 inches of mild steel at a five-inch standoff. The general appearance of the jets, as observed in the flash radiographs for all lots, indicates that the penetration at optimum frequency for all groups should be at the same level, and that the optimum frequency shifts progressively as the deformation angle passes from minus 15° to plus 45°. In Figure 6, the spin compensation frequency is plotted as a function of the deformation angle. Least square fits of the observed data based on flash radiographs of jets, and two sets of separate data obtained previously by Firestone[6,8] in penetration-rotation experiments for similar liners are given. The data obtained by the flash radiographic techniques are represented by curve 1, and the Firestone data by curves 2 and 3.

Flash radiographic techniques provide a more sensitive method of determining optimum spin compensation frequencies than the penetration-rotation experiments. The penetration performance curve is quite flat near the optimum frequency, and the precise frequency of compensation for the peak penetration is difficult to determine from this type of data. However, the distinguishing features of a spin compensation jet obtained from flash radiographs allow a more precise selection of the compensation frequency to be made.

The data collected at the Ballistic Research Laboratories cover a larger range of deformation angles than those represented by the Firestone experiments. Over the range of deformation angles covered by both the Firestone and BRL data, the optimum spin compensation frequency does not differ by more than five rps for any particular angle. The error in estimating the compensation frequency from flash radiographs is considered to be ± five rps. The curve represented by the more extensive Firestone data, curve 2, follows the BRL data rather closely (curve 1).

B. Non-destructive Inspection Technique

Results of the flash radiographic investigation have been correlated with results obtained in a separate investigation conducted by Gainer and Glass[9] of the BRL. Samples of rotary extruded liners taken from eleven lots used here were subjected to back-reflection x-ray diffraction studies at several different depths through the wall thickness of the liner in order to determine the preferred orientation in the crystal structure that is introduced by the method of manufacture. Measurements of differences in two intensity maxima in the preferred orientation were correlated with the optimum spin frequencies obtained from each liner type. Figure 7 is a plot of the optimum spin frequencies determined by the radiographs of each liner group vs the difference in intensity maxima. An approximately linear relationship resulted.

Further studies[9] have indicated that a complex relationship exists between the surface orientation and the orientation in the material under the surface. It is believed that the sub-surface orientation is the determining factor in the metallurgical spin compensation phenomenon.

(CONFIDENTIAL) IV. CONCLUSIONS

These experimental results indicate that, with present knowledge, liners manufactured by the rotary extrusion process can be compensated for rotation effects up to frequencies of 45 rps. Although the highest compensation frequency attained in these experiments was 35 rps, previous experiments using 105mm shear-formed liners have shown a compensation frequency limit of 45 rps[3].

The possibility of attaining higher optimum spin-rates by the rotary extrusion method of liner manufacture does not appear promising. Liners with deformation angles greater than 45° are difficult to produce with good dimensional quality. The liners of lot K (+ 45°) showed annular tool rings near the liner apex, and a group of 105mm liners with a 90° deformation angle had a considerable deviation from liner tolerances[16]. The optimum frequency for the cone with a 90° distortion angle was 20 rps[17]. The experimental evidence indicates that the deformation angle for maximum compensation frequency reaches an upper limit and then decreases with increasing deformation angle.

For the 90mm T300 HEAT round which requires an optimum compensation frequency of 25 rps, an inspection technique of the deformation angle measurement between the range of 15° to 35° is sufficient to obtain the required compensation frequency for this round.

Consideration should be given to geometrical fluted liners at lower spin compensation frequencies. Fluted liners[14] designed to compensate at 30 rps (90mm T108) have been tested and penetration performance was greater than that obtained with rotary extruded liners. For compensation at higher spin-rates, the fluted liner is necessary, since rotary extruded liners have not been shown to compensate above 45 rps in any caliber.

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T H Martin
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(UNCLASSIFIED) V. REFERENCES

1. Phebus, R. L., and Rassenfoss, W. O., Study of the Effects of Annealing on the Penetration Performance of Copper Shaped Charge Liners, BRL 837, Symposium Transactions, Nov. 13-16, 1951.

2. Zernow, L. Plastic Behavior of Polycrystalline Metals at Very High Strain Rates, Doctoral Dissertation, Johns Hopkins University, 1954.

3. Zernow, L., and Simon, J., Flash Radiographic Study of Spin Compensation in Shear Formed Liners, Shaped Charge Journal, Vol. 1, No. 1, July 1954, p.100.

4. Zernow, L., and Simon, J., High Strain Rate Plasticity of Liner Materials and Jet Behavior, BRL No. 934, August 1955. 72035

5. Supplement to the Sixth Progress Report of the Firestone Tire and Rubber Co. on Contract DA-1-33-019-501-ORD-(P)-16, Design and Development of Cartridge, HEAT, T300 for 90mm Gun, T119, October 1953.

6. Thirteenth Progress Report of the Firestone Tire and Rubber Co., Design and Development of Cartridge, HEAT, T300 for 90mm Gun, T119 under Contract DA-1-33-019-501-ORD-(P)-16, Project TA1-1460, May 1954.

7. Forty-first Progress Report of the Firestone Tire and Rubber Co., on BAT Project, Contract Nos. DA-33-019-ORD-33 and DA-33-019-ORD-1202, December 1953, pp.43 and 46.

8. Fifty-sixth Progress Report of the Firestone Tire and Rubber Co., BAT Project, Contract DA-33-019-ORD-1202, March 1955.

9. Cainer, M., and Class, C., Forthcoming report on the investigation of metallurgical spin compensation.

10. Kronman, S., Simon, J., et al., A Triple-flash Field Radiography System for Studying Jets from Large Shaped Charges, BRL Report No. 659, March 1955.

11. Zernow, L., and Simon, J., Flash Radiographic Study of Special Liners for Shaped Charges, BRL Report No. 955, June 1955. 74217

12. Craft Manufacturing Progress Reports, Contract No. DA-28-017-501-ORD-2187, Investigation of Shaped Charge Rotary Extruded Liners.
    a. Aug. 16, 1956
    b. Sep. 14, 1956
    c. Oct. 14, 1956
    d. Nov. 14, 1956
    e. Dec. 14, 1956
    f. Jan. 14, 1957

13. Unpublished data obtained from Mr. C. Zglenicki of Picatinny Arsenal, on lots A, B, C, D, E and J which have been fired in penetration vs rotation experiments.

14. Letter from Firestone to BRL, File No. CI-58-1303, dated 11 April 1958, Static Penetration Test of T-300E53 Production Engineering.

15. Letter Contract DA-28-017-ORD-2187, dated 29 May 1958, Picatinny Arsenal, File No. CI-58-1663.

16. Firestone Tire and Rubber Co., DA-33-019-ORD-2037, Feb. 1956.

17. Simon, J., and Martin, T., Rotary Extruded Liners with 90° Deformation, OCSCRR No. 4-56, Oct. 1956.

TABLE I

MANUFACTURING PARAMETERS AND OPTIMUM PERFORMANCE DATA OF 90MM T108E40 ROTARY EXTRUDED LINERS

Manufacturing Parameters					Performance Data		
						Penetration Performance*	
Lot No.	Mandrel Rotation Rate (RPM)	Mandrel Rotation Direction	Feed Rate Inches/minute	Deformation Angle (Degrees)	Estimate of Optimum Freq. Based on Radiographs (RPS)***	Opt. Freq. (RPS)	Penetration into mild steel at 5" Standoff (inches)
A	1800	Clockwise	4.85	-15	-25	-20	16.3
B	1800	Clockwise	2.67	-10	-20	-20	16.8
C	1800	Clockwise	.78	- 5	- 8	- 8	16.3
D	1800	C.Clockwise	1.04	0	+10	+10	16.7
E	1800	C.Clockwise	1.13	5	+20	+10	17.2
F	1800	C.Clockwise	1.78	10	+15	**lots F through K indicate a range of frequencies from +15 rps to +46 rps	penetration level for lots F through K is 16.5 inches
G	1800	C.Clockwise	2.49	15	+20		
H	1800	C.Clockwise	3.74	20	[illegible]		
I	1800	C.Clockwise	5.67	25	+22		
J	1800	C.Clockwise	11.70	35	+25		
K	1800	C.Clockwise	17.02	45	+35		

* Penetration Performance
All data supplied by C. Zglenicki, Picatinny Arsenal[13,15].

** Penetration-Rotation firings for Lots F through K indicate a range of optimum frequencies for a given deformation angle.

*** Jet radiographs allow greater selectivity of the optimum compensation frequency based on the physical appearance of the jet elements at a particular spin-rate.

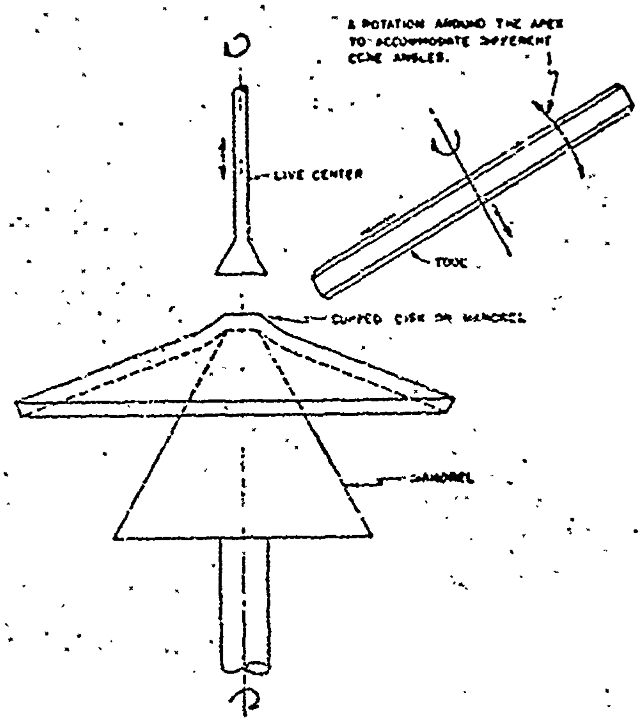

FIGURE 1- A SKETCH SHOWING THE RELATIVE POSITIONS OF THE MANDREL, LIVE CENTER, TOOL AND MATERIAL AT THEIR STARTING POSITION. THE ARROWS INDICATE THEIR MOVEMENTS AND DEGREES OF FREEDOM IN THE ROTARY EXTRUSION PROCESS.

FIGURE 2 - SCRIBING AND MEASUREMENT OF DEFORMATION ANGLE "θ" AS DETERMINED BY MANUFACTURER.[12]

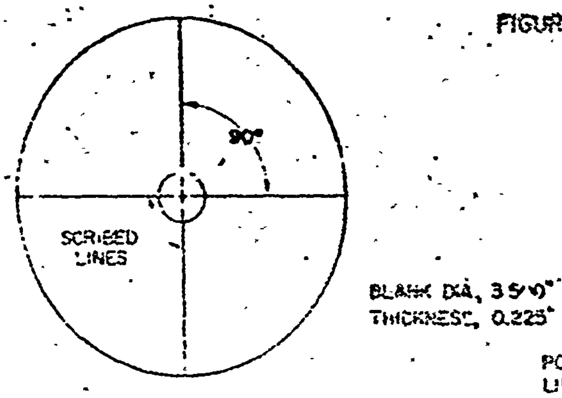

FIGURE 2a - METHOD FOR SCRIBING BLANKS

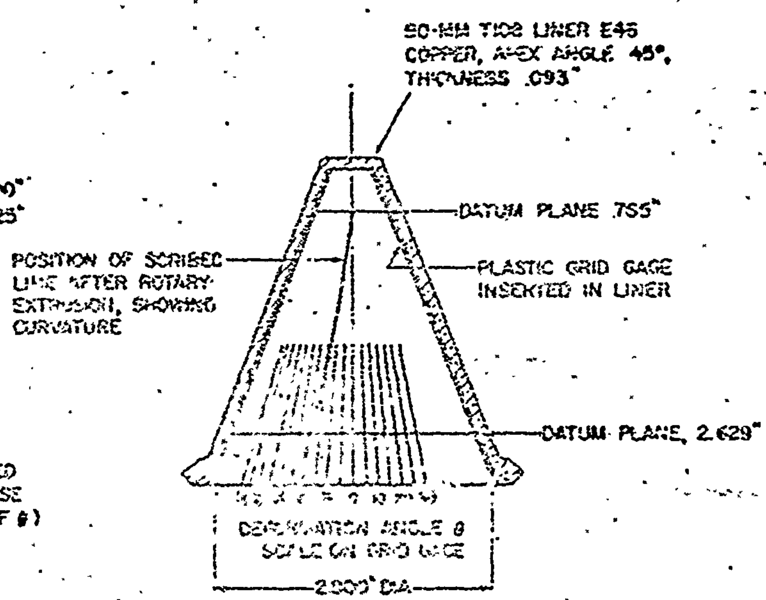

FIGURE 2b - SIDE SECTIONAL VIEW OF [illegible] EXTRUDED [illegible]

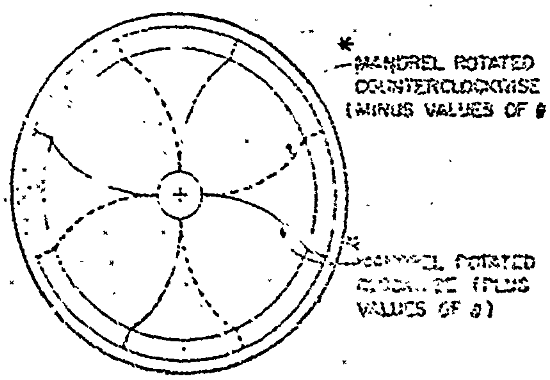

FIGURE 2c - VIEW OF ROTARY EXTRUDED LINER MADE WITH SCRIBED BLANK.

(VIEWED FROM BASE SHOWING POSITION OF SCRIBED LINES)

* MINUS VALUES θ GIVE NEGATIVE SPIN COMPENSATION.
PLUS VALUES θ GIVE POSITIVE SPIN COMPENSATION.

NOTE: THE CONVENTION [illegible] OF [illegible] IF THE TEST [illegible] VIEWED FROM THE [illegible] TO A RIGHT HAND TWIST OF RIFLING OF GUN.

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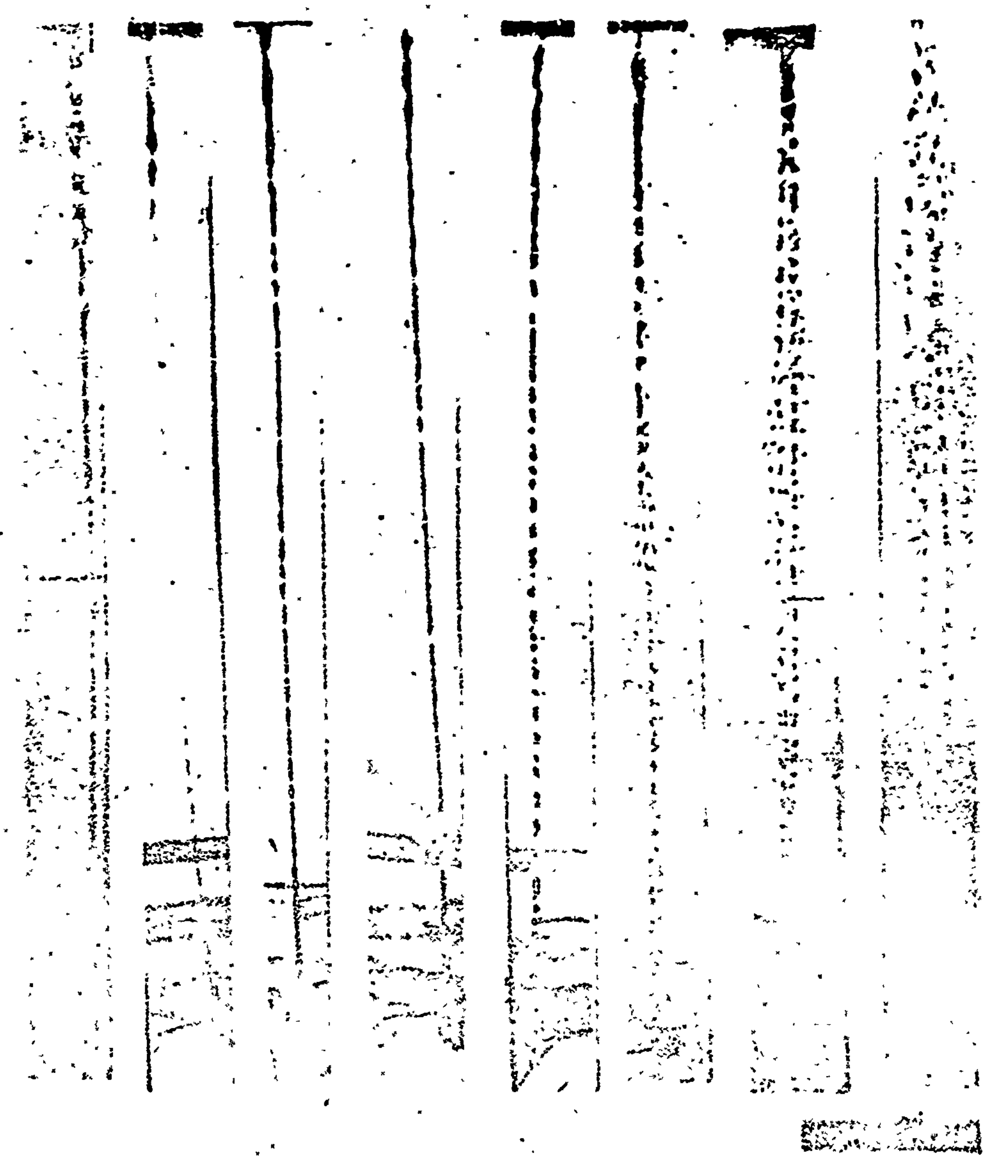
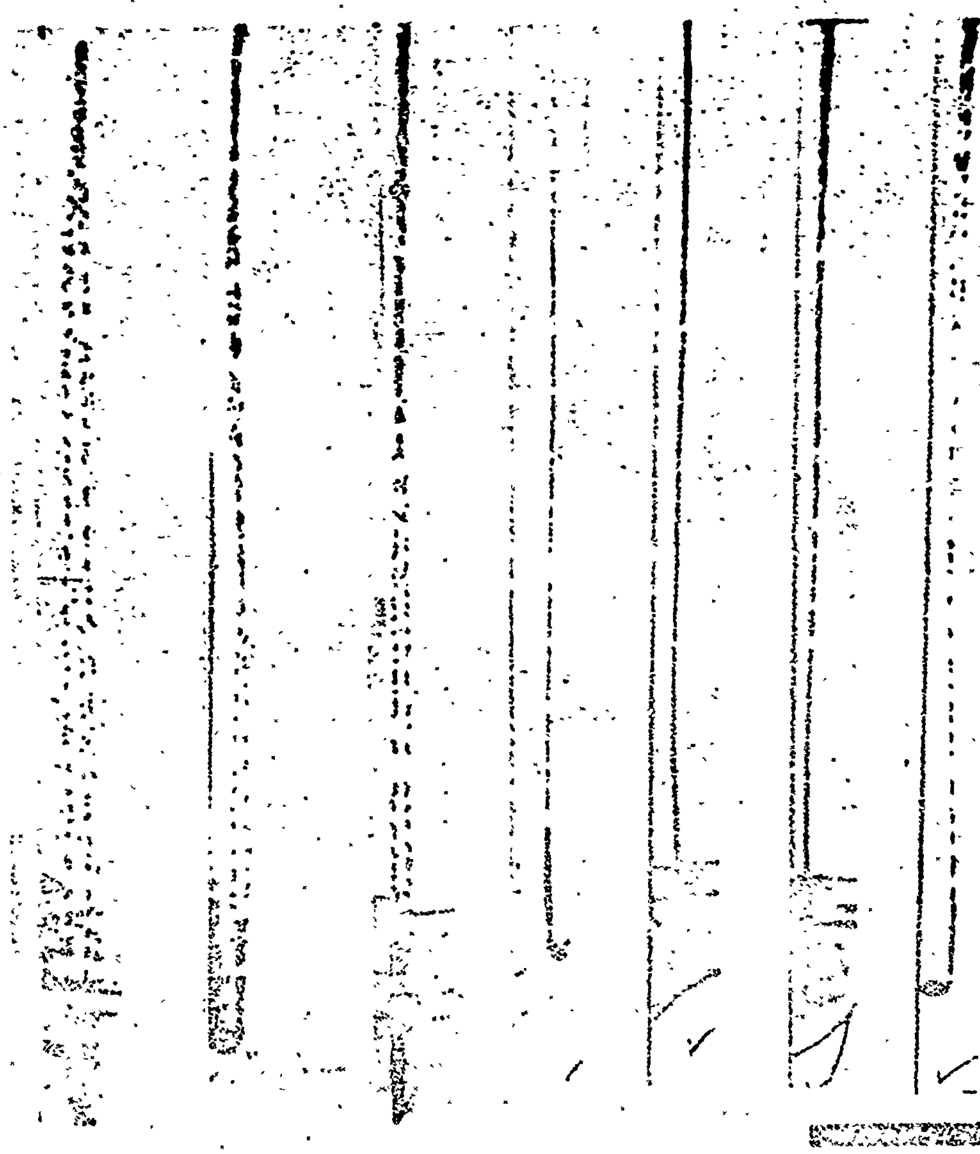


FIGURE 3 - FLASH RADIOGRAPHS OF JETS FROM LOT A AT VARIOUS FREQUENCIES OF ROTATION, WITH A NOMINAL DEFORMATION ANGLE OF -15°, (a) -60 RPS, (b) -45 RPS, (c) -30 RPS, (d) -15 RPS, (e) NON-ROTATED, (f) +15 RPS, (g) +30 RPS, (h) +45 RPS



a b c d e f g

FIGURE 4 – FLASH RADIOGRAPHS OF JETS FROM LOT K AT VARIOUS FREQUENCIES OF ROTATION WITH A NOMINAL DEFORMATION ANGLE OF +45°. (a) –30 RPS, (b) –15 RPS, (c) NON-ROTATED, (d) +15 RPS, (e) +30 RPS, (f) +45 RPS, (g) +60 RPS

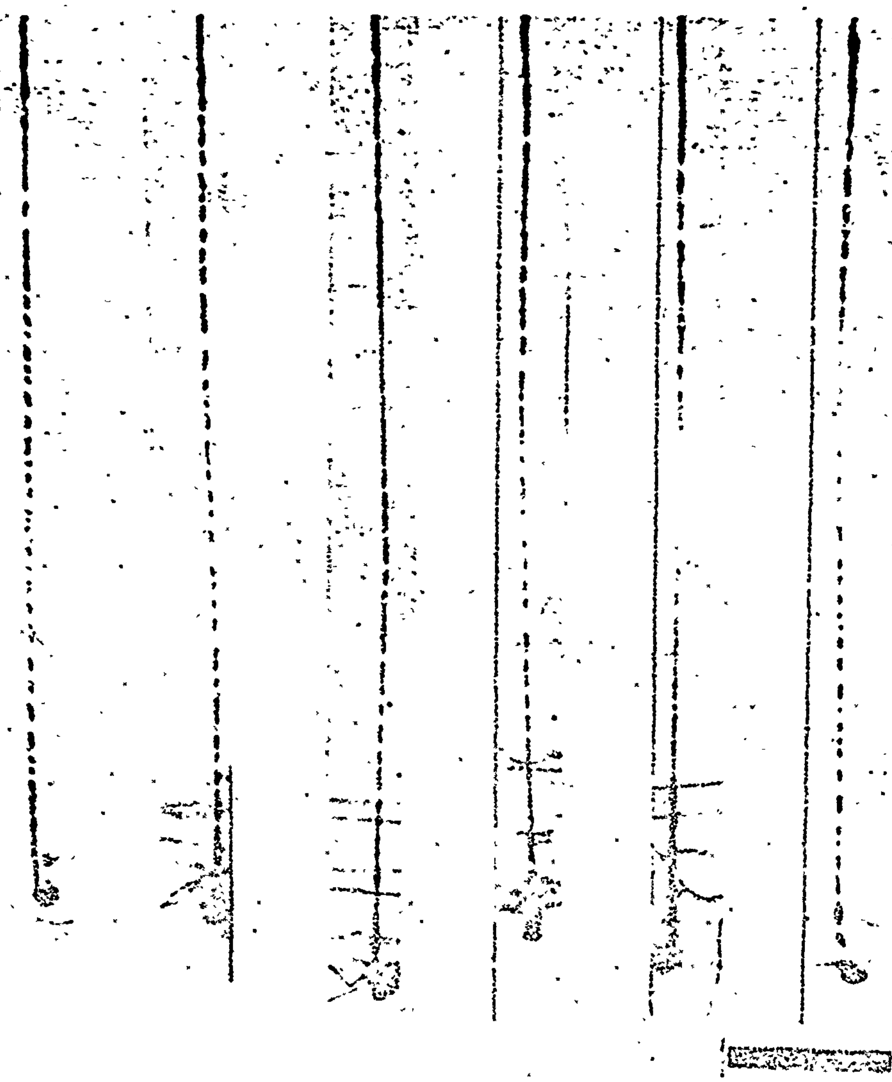


FIGURE 5—FLASH RADIOGRAPHS OF JETS OF THE ELEVEN LOTS OF ROTARY EXTRUDED LINERS. THESE ROUNDS WERE FIRED STATICALLY WITHOUT ROTATION. THE JETS WITH GREATEST AMOUNT OF FRAGMENTATION INDICATE LINERS WITH HIGHEST COMPENSATION FREQUENCY. THE RADIOGRAPHS ARE VIEWED FROM LEFT TO RIGHT WITH THE DEFORMATION ANGLE CHANGING FROM -15° TO +45°.
(a) LOT A -15°, (b) LOT B -10°, (c) LOT C -5°, (d) LOT D 0°, (e) LOT E +5°, (f) LOT F +10°

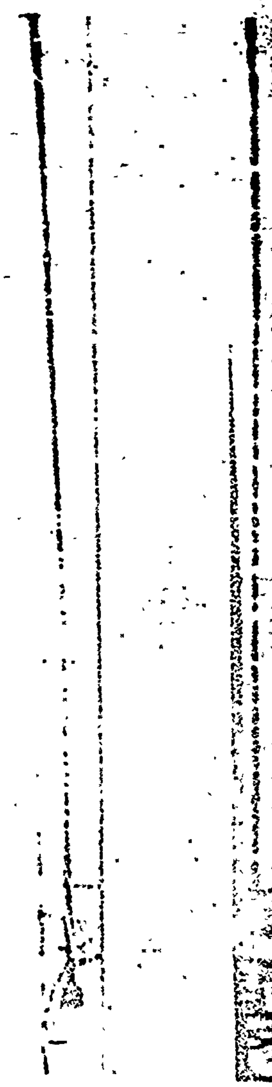
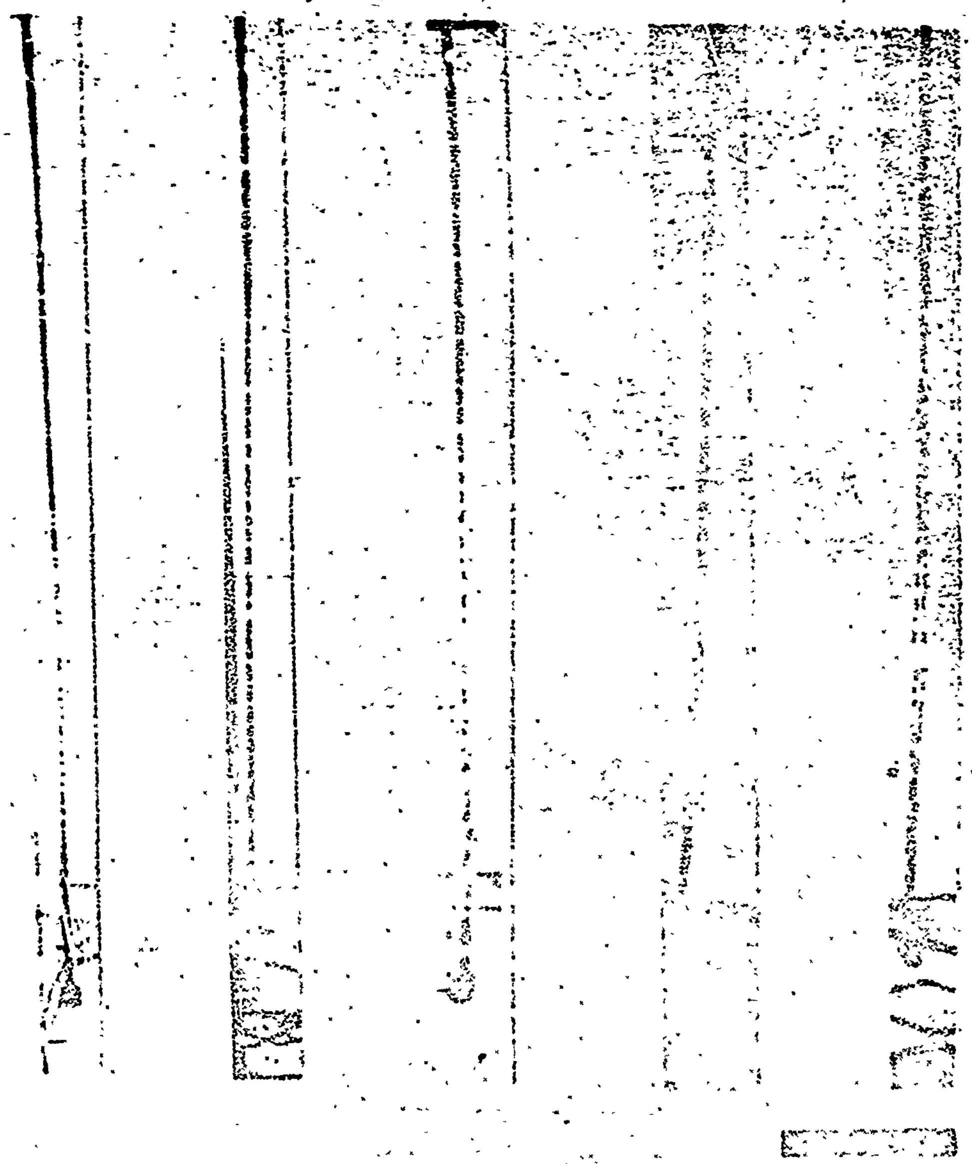


FIGURE 5 CONTINUED
(g) LOT G +15°, (h) LO



g h i j k

FIGURE 3 CONTINUED
(g) LOT G +15°, (h) LOT H +20°, (i) LOT I +25°, (j) LOT J +35°, (k) LOT K +45°

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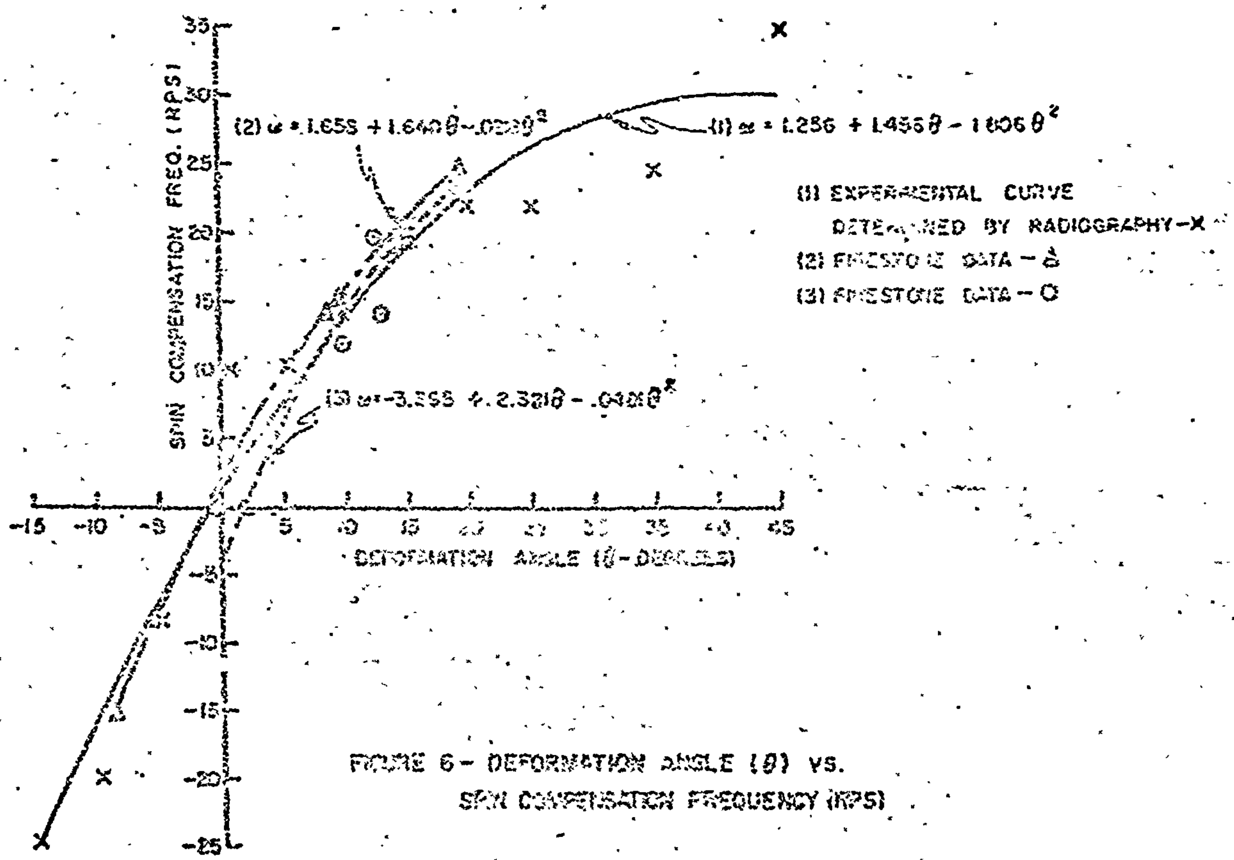

FIGURE 6 - DEFORMATION ANGLE (θ) VS. SPIN COMPENSATION FREQUENCY (RPS)

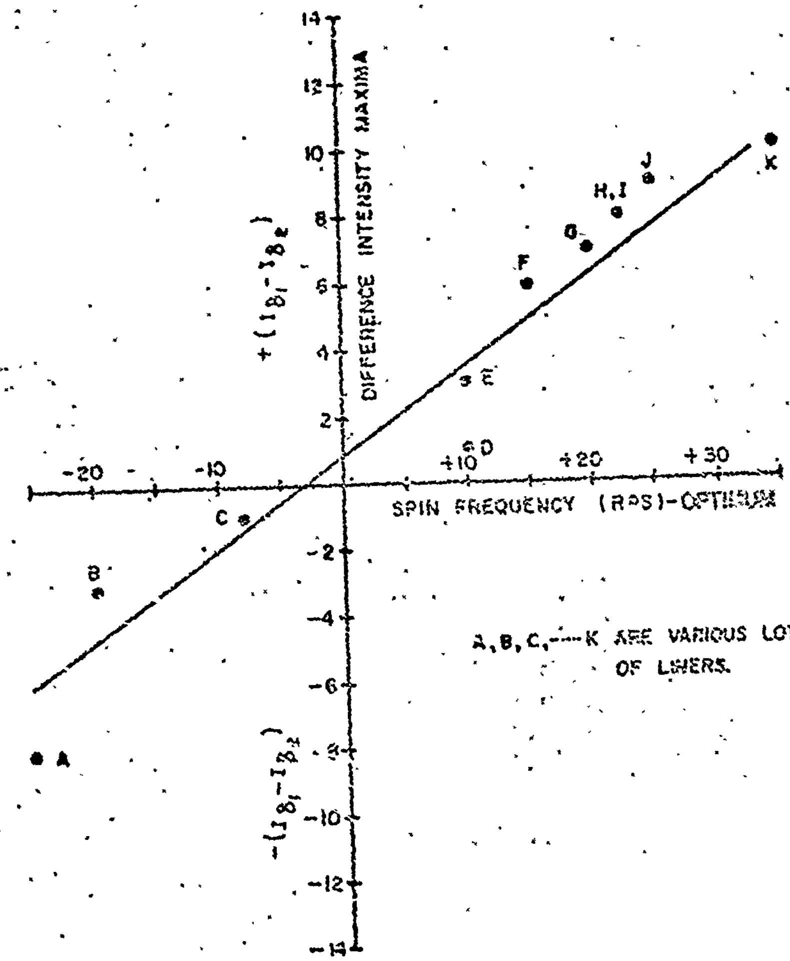

FIGURE 7. DIFFERENCE IN INTENSITY MAXIMA VS. SPIN FRE-QUENCY. SPIN RATES ESTIMATED FROM RADIOGRAPHS OF JETS FROM ROTATED SHAPED CHARGES. INTENS-ITY MEASUREMENTS OBTAINED BY "BACK REFLECTION X-RAY TECHNIQUES" (5).